Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 132 (2015) 1081 – 1088
Procedia Engineering
www.elsevier.com/locate/procedia

The Manufacturing Engineering Society International Conference, MESIC 2015

Eco-Process Engineering System for composition of services to optimize product Life-Cycle (EPES)

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Abstract

This document is presenting the results of EPES (Eco Process Engineering System). EPES is intending to enable the industrial companies to generate innovative dynamic life-cycle services oriented to a continuous improvement of product operation and end-of-life use. The project running along three years and a half (September 2011 – February 2015) under the 7th Framework Programme of the European Commission, has developed a set of ICT tools plus a comprehensive methodology, which has been tested and validated through three Business Cases in three different industrial sectors, namely wind mills, energy and aeronautics.

Peer-review under responsibility of the Scientific Committee of MESIC 2015

Keywords: Eco-innovation; product life-cycle management (PLM); business process management (BPM); virtual collaborative networks (VCN); sustainability intelligence (SI).

1. Introduction and objectives

This paper is presenting the final achievements of Project EPES running under the 7FP (ICT-2011-285090). A paper based on EPES has been previously presented to the MESIC 2013 Conference [1] being the project right starting. EPES is now finalised (September 2011 – February 2015) and project's final results are presented together with a short overview of one of the business cases. EPES project has developed a set of tools, constituting an Eco Process Engineering System enabling the industrial companies to generate innovative dynamic life-cycle services oriented to a continuous improvement of product operation and end-of-life use.

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Peer-review under responsibility of the Scientific Committee of MESIC 2015
doi:10.1016/j.proeng.2015.12.599

New industrial products surely benefit from the possibilities of incorporating incoming and more sustainable best available technologies [2]. However, the highest impact results in extending the operating life of existing products towards the "Long Life Eco-products" concept [3] [4]. In this sense, traditional maintenance systems just cares on replacing worn out parts without a knowledgeable analysis of the upgrading possibilities that may rise from the concepts of sustainable development. Thus, EPES eco engineering system goes in fact far beyond these traditional maintenance systems, incorporating knowledge coming from the environmental and social bottom lines aiming at achieving a continuous improvement of product operation and end-of-life use on several sustainability aspects, such as:

- Improving energy efficiency, environmental impact, waste management, etc. during the operating life of the product
- Enhancing the useful life span of the product
- Improving environmental impact by disposal at the end of life: increasing re-use (re-manufacturing, overhauling, components transferring, etc.) and reducing waste
- Increasing productivity (availability), reliability, maintainability
- Reducing overall costs in operation
- Improving working environment: more friendly products, easier to use and maintain, and improved workers' health and safety conditions
- Collecting and storing knowledge on the products by means of an ecosystem that integrates all the actors: producers, customers and users, maintenance service, technology providers, experts and researchers, aiming at product design improvement by knowledge reuse

Summarizing, EPES focuses on the research and development of novel methods and tools for the conceptualization of an eco-process engineering system, which constitutes a comprehensive platform that enables a dynamic composition of "eco-advice" services adaptable to the different products and operating conditions. This framework leverages a sustainable life-cycle management of existing products in operation.

1.1. EPES objectives

The strategic objective of the EPES project has been to develop a novel eco process engineering system, which constitutes a comprehensive platform enabling a dynamic composition of services adaptable to the different products and operating conditions, supporting the Product Service System.

This novel service oriented framework is intended to allow industries to evaluate the performance of engineered products considering their whole lifecycle rather than only early stages such as design and manufacturing, thus enabling the capitalization of trustable global and local sustainability intelligence. Product engineering teams can exploit this intelligence to adapt design, operation and disposal strategies through managed "eco-constraints" relevant to their market contexts.

Both manufacturing processes and maintenance services require software integrating solutions being able to capture and process information from various actors and different operational phases with the objective of enhancing efficiency and improving sustainability performance from a life-cycle perspective. Static, isolated systems generally in use cannot react fast and flexibly enough, as there are no appropriate services for capturing knowledge and putting it to practical use in relevant time. EPES novel eco process engineering system supports improving the performance of highly customized industrial products, processes and services during their life cycle, in cases in which no standard, off-the-shelf solutions can be applied. The system is formed by a comprehensive platform enabling dynamic composition of software services adaptable to the different products and operating conditions, supporting the Processes, Products, and Services (PPS), which extends the well-known Product-Service System taking into account also processes.

EPES system consists of:

- A set of ICT tools
- A methodology and working handbook

2. EPES concept

EPES conceptual development, showed in Fig. 1 below, has been driven by a generic scenario obtained from analyzing detailed requirements of three industrial application scenarios. This ensures industry relevant development of EPES methodology and services/modules as the requirements are directly derived from three different use cases and analyzing the current state of the art. Based on these requirements, overall EPES reference architecture, features and functionality required for EPES solutions are derived.

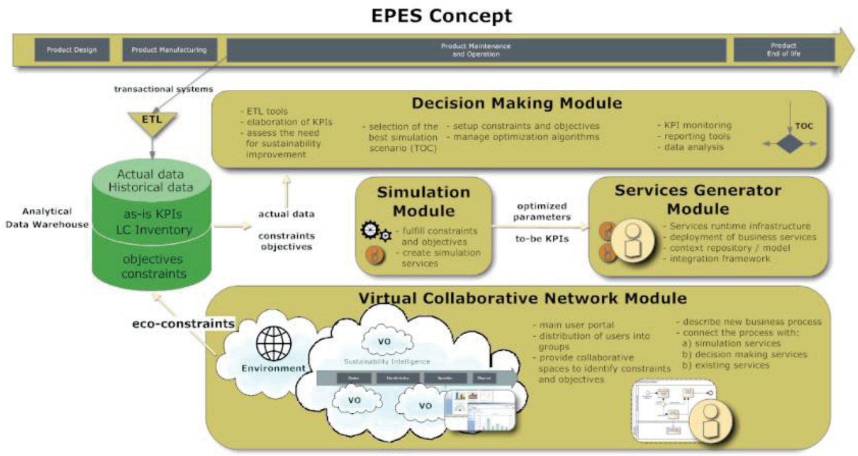

Fig. 1. Basic EPES concept

2.1. EPES concept in Product Service System concept

The EPES system enables managers and engineers of any knowledge field to initiate collaboration with involved parties in contraposition to the "old-way" of working, where each stage of product life cycle individually does own analyses and decisions. EPES "collaborative-way" of product life cycle management is shown in the following Fig. 2.

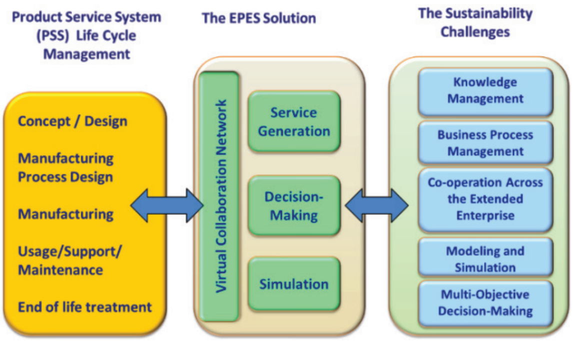

Fig. 2. Collaborative Product Life Cycle Management with EPES. The "Big Picture"

As a solution to the highly complex and multi-disciplinary problems of sustainable business operation, the EPES platform is most of all a platform for business process management, with a target on businesses that need to routinely apply complex analysis and modelling operations in the course of their everyday work.

The EPES platform integrates complex modelling and simulation services into business processes and enables easy and streamlined execution of those services on a server platform. Access to these services is brought into the context of a collaborative working environment, which allows efficient communication between the participants of the business processes. It also includes functionality for management of enterprise-wide knowledge that is related to the sustainability of the operation of the extended enterprise. This knowledge consists both of textual documentation concerning the operations of the enterprise, and of numerical data, which can be used to quantify the sustainability aspects of the business operation.

The platform can also serve more complex structured data, such as CAD drawings, product models, etc. However, as a research prototype, the EPES platform does not reach the level of a fully functional engineering data management system.

The five main features provided by the EPES platform are as follows:

Knowledge Management

The main component of the knowledge management functionalities of the EPES platform consist of:

Enterprise Content Management (ECM) platform, which provides a structured storage space for all documentation across the enterprise.

Relational Database for storing numeric data, such as Key Performance Indicators (KPIs), which can be configured using a web-based user interface.

Ontology-based Context Repository, which is a semantic database and a supporting module that collects metadata about user activities.

Business Process Management

The business process management (BPM) features of the platform enable its users to both document and to manage the execution of business processes within the enterprise. The EPES Methodology defines a BPM cycle, in which business processes are designed, executed, monitored and analyzed in a continuous cycle of gradual improvement. An important concept in the provision of these services is the Service Generation Module (SGM), which provides support for the configuration of existing IT components, such as computational tools or transaction systems, into EPES Services.

Internal and External Communication

In order to facilitate the coordination between experts of various fields, whose contribution is necessary in the process of the gradual improvement of the sustainable business, the EPES platform includes features for interpersonal communication in the form of Web 2.0 features, such as messaging, discussion forums, calendar management, etc. These features are provided by the integrated ECM system. The platform allows users to flexibly create new issue-specific workspaces so-called Collaborative Spaces, in which both data and communication are kept in the same well-defined context. The system allows users to share notes that link directly to the content within the document repositories of the workspaces.

By allowing access to people outside the home organization, the platform allows efficient communication between interest groups within the extended enterprise. Participation of both the supply chain and the customer base is possible.

Anticipation of Future Effects

As sustainability is an inherently holistic view-point, it must be tackled throughout the whole life cycle of the PPS system. From a direct cause-and-effect point of view, the major (negative) contributions to sustainability are often produced by the late stages of the life cycle, especially in systems that involve high energy use (or production) in the use stage of the system.

On the other hand, from the decision-making point of view, the most pronounced effects are achieved in the early stages of the system life cycle. This need to make decisions that affect the performance of the system in the far future makes it absolutely necessary to have access to good quality modelling and simulation tools. One problem is that modelling and simulation are inherently hard endeavors, which requires both considerable expertise and highly specialized software tools.

Multi-Objective Decision-Making

The ultimate pivot point in the part to continuous improvement in sustainability is the point of decision-making. In order to enhance the continuous improvement process, there are two things that can be addressed:

The rapidity of the decision-making cycle, i.e. how often new improvements can be introduced.

The quality of the decisions that are made, i.e. how big steps of improvement can be taken.

These two aspects are often at odds with each other. As a holistic endeavor, sustainability presents additional challenges for decision-making in the form of introducing additional criteria into the process. When eco-indicators are adopted as development targets in a business, there are usually several different ecological aspects that need to be taken into account simultaneously, in addition to the ever-present traditional economic aspects. Also the widening of the point-of-view into larger part of the system life cycle presents decision-makers with the need to balance the contributions from each life-cycle stage simultaneously.

3. EPES ICT solution

As said above, EPES provides novel ICT solutions to generate services to improve the performance of highly customized industrial processes, products and services (PPS) during their life cycle. An important factor influencing this improvement process is the dynamic, flexible, and customizable nature of the software services that back up the life cycle. Four modules, which can be combined and embedded in the decision-making processes in companies from different sectors, are the key components of the EPES solution, as follows:

Virtual Collaborative Network Module (VCN): Serves as Virtual Factory Infrastructure, enabling Business Process Interoperability support, Business Optimization Opportunities Tracking, as well as Eco-constraints and Objectives Tracking. These functionalities are supported by a content repository, a text mining suite for analyzing documents stored in the repository (for discovering important words, association rules, similarity among documents, classifying documents) and a workflow engine.

Service Generator Module (SGM): Provides a service runtime infrastructure for EPES, enabling the configuration and re-configuration of deployed services and the extraction of the context-related information. SGM provides the methods to access the EPES Services, namely, through the SGM aggregator/cockpit or through the VCN workflow engine.

Decision Making Module (DMM): Helps decision makers use data and models to identify and solve problems through a decision making process. This module supports KPIs calculation aiming at fulfilling an objective or eco-constraint derived from the Collaborative Spaces.

Simulation Module (SM): Responsible for providing capabilities for automated execution of pre-defined simulation or other computational processes. The module provides methods to calculate as-is KPIs, guidelines to analyze KPIs with analytical tools and methods to optimize a simulation to find an optimal trade-off among several objectives.

The main innovation of EPES is holistic, modular and extendable system that allows the easy (re)configuration of services in order to react flexibly to relevant insights and to meet varying requirements along the PPS life cycle. To build such innovative solution, EPES combines and extends a number of advanced tools.

4. EPES methodology

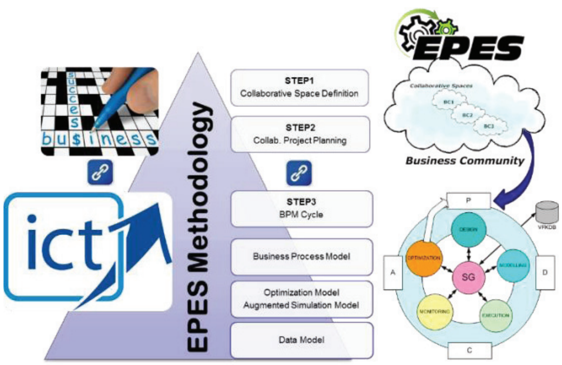

Fig. 3. Visual overview of EPES Methodology

Fig. 3 provides an overview of the EPES Methodology, which supports the application or integration of the EPES Full Prototype components to any possibility of operation that the EPES platform allows. The methodology supports practitioners to understand EPES system capabilities and its implementation possibilities.

As a precondition to effectively adopt the EPES Methodology, the organizational structure should be oriented to processes and functional areas so as to streamline the future assignation of manual tasks to the involved actors. This involves the promotion by the senior management of a corporate cultural change through leadership and a consistent process management policy in line with the corporate vision. This cultural adaptation includes the establishment of a breeding environment, where knowledge sharing and, therefore, collaboration is promoted and compensated. In this sense, well defined roles should be created to support the introduction of the new approach. Furthermore, organizations collaborating in a Virtual Factory environment have to be aware that they are sharing data, documents, information and knowledge outside the boundaries of their enterprises and this knowledge may be protected under Intellectual Property Rights (IPR).

EPES methodology provides the potential practitioners with full guidance and awareness about:

Collaborative Spaces in which the methodology shall be applied

Critical success factors of the application scenario

Evaluation of the necessity for its application: Study about the needs for establishing business networks to leverage process optimization following EPES approach

The optimization project definition and planning within EPES business networks

BPM [5] approach application

The methodology provides a comprehensive and structured approach on how to adopt the EPES solution by the Industrial Community.

5. Business cases

EPES has been validated and demonstrated through three Business Cases and demonstrators. The industrial partners, supported by the RTDs have elaborated the 3 BCs addressed in terms of definition of relevant aspects in environment impact and life cycle management to be included in the product/process design, and the users have identified which areas in their organizations were the most interesting and promising ones in order to be involved in the development/evaluation processes, i.e. for which processes within the life cycle the developed software components should be explored in order to test and assess the project results.

The project has been applied to the following sectors:

Wind mill engineering (BC1): The project results are helping to generate and develop high value added services to the windmill farms maintenance

Energy (BC2): The project has developed supporting services easily adaptable to customer specific needs, which facilitate the analysis and maintenance of electrical cable systems with respect to a secure use of increasing cable capacity, due to the increasing share of renewable energy in the European Union

Aeronautics (BC3): The project results have helped identify eco-constraints relevant to the manufacturing systems assessment capability at the right point in time in the aeronautics sector

Just giving a short reference of the first business case (BC1) it can be said that it has been led by The Wind Farm division of TAMOIN, SL, which is an industrial company located in Spain specialized in rendering services for the installation and maintenance of wind farms. TAMOIN has several regional offices, drawing a diagonal from the northwest to the southeast of Spain. Each one is responsible for several wind farms, depending on the number of wind turbines and the distances between the wind farms.

TAMOIN maintenance programs are focused on:

Predictive Maintenance (condition based monitoring), triggered by a predicted failure

Preventive Maintenance, which are foreseen and planned with a defined frequency, before the component needs to be replaced due to failure or underperformance. These activities are scheduled (long and short term scheduling) with an horizon of the whole year first and then an horizon of seven days every week

Major Corrective Maintenance, released for scheduling upon the localization of a failure, requiring auxiliary means

Minor Corrective Maintenance, released for immediate scheduling upon the localization of a failure, requiring only spare parts as replacing components

Retrofits and Overhauling, released by high level decisions

A regional office located in Spain was selected for the development of this Business Case, comprising three wind farms with an average of 60 wind turbines per wind farm. Seven maintenance crews are in charge of the maintenance operations in the selected regional office. The application of the EPES solution to the BC1 is a showcase aimed to support TAMOIN in:

Providing high added value maintenance engineering services to their clients through a trustable decision support system

Improving data capture and knowledge management, allowing the integration of maintenance data with wind turbines operation data aimed at its joint exploitation

Obtaining a system of business indicators to track continuous improvement activities

Improving the planning of maintenance activities, taking into account the optimal time for required maintenance of each component due to the failure probability of each of them

Improving maintenance activities efficiency, reducing times, costs and improving availability

Streamlining and standardizing TAMOIN procedures and processes

6. Results and discussion

The Eco-Engineering approach provided by EPES, lies on two steps; on the one hand, the sustainability KPIs derived from Sustainability Intelligence sources and, on the other hand, on the application of Life Cycle Assessment to those KPIs.

To assess the environmental performance of the EPES Services contained in a Collaborative Space, the Life Cycle methodology, commonly known as LCA, is used. A full scale LCA analysis would be a manual step, done by dedicated experts. There are high expertise requirements during LCA analysis steps. Secondly, current LCA software is desktop based engineering applications. The LCA analysis could be done before using EPES services, thus LCA analysis data are input for EPES service, or it can be a manual analysis step during the EPES service.

Life cycle assessment (LCA) is a methodological tool used to quantitatively analyze the life cycle of products/process/services (PPS). The four phases of LCA are the Goal and Scope definition phase, Inventory Analysis, Impact Assessment and Interpretation.

LCA expertise is required in every step of LCA. The goal and scope definitions are essential parts of LCA and help in setting boundaries and communicating results. The goal and scope as well as functional unit need to be defined in every study, and they are dependent on the product system under study. One of the biggest problems in doing LCA is to get high quality data for Life cycle inventory analysis. Data quality has a major role in the evaluation of the reliability of the results. The life cycle assessment method is an iterative modelling process, and the results are therefore only as valid as the background data. The selection of impact categories depend on product system (impact categories which are important for one product, might be irrelevant for another) and expertise is needed. The end of life stage is often the most uncertain part of the LCA, but it need to be included in cradle to grave studies. Recycling ratios, end-of-life treatments, etc. also vary depending on the product system. Additionally high expertise is needed to do and interpret the results of LCA studies.

After the Goal and Scope have been determined and data has been collected, an Inventory result is calculated. Thus, the Life Cycle Inventory (LCI) is the phase of the LCA in which data is collected for inputs and outputs for all processes of the product system. This inventory result is usually a very long list of emissions, consumed resources and sometimes other items. The interpretation of this list is difficult. Consequently, a Life Cycle Impact Assessment (LCIA) procedure is needed. In order to perform a LCIA, several methods exist at scientific level. EPES Project leverages the ReCiPe method, which was designed to help with this interpretation. ReCiPe was developed to combine the advantages of the CML 2001 and Eco-Indicator 99 methods. The advantage of the CML method lies on its scientific soundness, while the advantage of the Eco-indicator 99 resides in its ease of interpretation. The ReCiPe method transforms the Life Cycle Inventory results into a limited number of indicator scores. These indicator scores express the relative severity on an environmental impact category. ReCiPe determined indicators at two levels:

Eighteen midpoint indicators

Three endpoint indicators

The procedure requires each user to choose at which level he / she wants to have the results:

Eighteen robust midpoints, which are relatively robust, but not easy to interpret

Three easy to understand, but more uncertain endpoints

These KPIs are fed into the EPES system in order to track and measure the continuous improvement that is provided by the EPES Services from the environmental perspective.

7. Conclusions

The key added value of the EPES solution and the progress beyond the State of the Art derives essentially from having an overall integrated, holistic, modular and extendable solution that allows the easy (re)configuration of services in order to react flexibly to relevant insights and to meet varying requirements along the PPS life cycle. By this, EPES responds to the companies' need for moving from static isolated systems to a more flexible and loosely coupled system applicable along the whole PPS cycle.

Thus, EPES Methodology provides a general approach to create a Collaborative Space, select and standardize a business process and model the optimization services that will support the improvement of this process. The general methodological approach, which could be applied to any generic Business Case (or Collaborative Space), involves the iteration throughout several steps that eventually build-up a Business Process Management (BPM) cycle. Each of the steps was designed to focus on the required tasks to dynamically compose EPES Services for supporting product operation and end-of-life cycle, concentrating on achieving more sustainable management of products and services. This approach addresses to the Industrial community aiming at the area of eco optimization (e.g. energy consumption) along production / processes life cycle, since it includes an applied approach for facing industry related problems within Virtual Factories and Enterprises domain.

EPES methodology contains the power of guiding some members organized in a Collaborative Space to improve their processes or critical processes in an innovative approach on how to combine advanced technologies to enhance eco-constraints use considerations in manufacturing and engineering industry for product/process life cycle management.

Moreover, the methodology supports the coordination and development of EPES ICT System and its integration. It transforms EPES ICT platform into a powerful System for industrial practitioners to successfully examine processes, create new ones, improve them, measure their impact, and evaluate the results in order to generate information (knowledge) that will be useful to share with other partners in certain conditions so as to make it possible to grow together. In this regard, EPES system will help developing projects and consortiums and will save time to other communities that would come up with similar dilemmas.

Acknowledgments

We want to acknowledge the European Commission for supporting this project under the FP7 umbrella as well as all the partners in the consortium.

References

[1] M. Sorli, A. Armijo. EPES: Engineering System for Optimisation of Product life-cycle through adapted eco-services. Proc. MESIC 2013, Zaragoza (Spain) 2013

[2] C.A. Antonio, C. Castro, J. Davim. Optimisation of multi-pass cutting parameters in face-milling. The International Journal of Advanced Manufacturing Technology, 44 (2009), pp. 1106–1115.

[3] A.W. Head and Y. Lu, Revolutions and Evolutions in Manufacturing Engineering. Proc. MESIC 2009, Alcoy (SPAIN), 2009.

[4] H. G. Lemu. Study of Capabilities and Limitations of 3D Printing Technology. Proc. of MESIC 2011: 4th Manufacturing Society International Conference. Cádiz, Spain, 2011.

[5] Armijo, A., & Sorli, M. (2014). Interoperable Process Engineering System for Collaborative Optimization of Product Life-Cycle. In Y. Charalabidis, F. Lampathaki, & R. Jardim-Goncalves (Eds.) Revolutionizing Enterprise Interoperability through Scientific Foundations (pp. 166-191). Hershey, PA: Business Science Reference. doi:10.4018/978-1-4666-5142-5.ch008